# The United States Measurement System Assessment as a Foundation for the Characterization of Nanomaterials Measurement Needs

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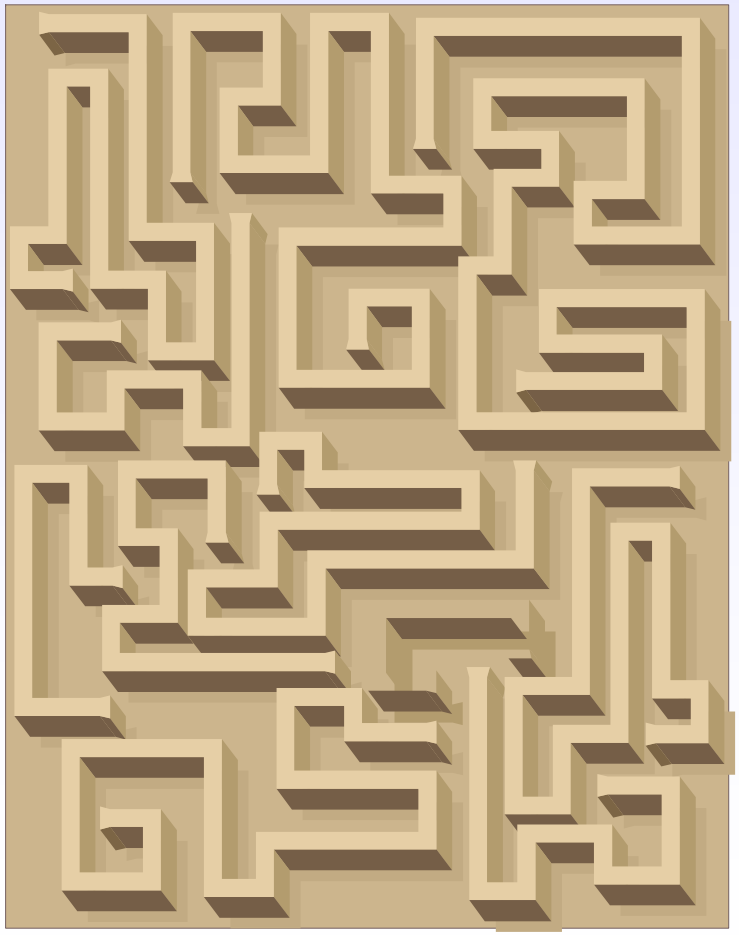
# Outline

- What is the U.S. Measurement System (USMS) ?
- Why Assess the USMS?
- How do we Assess the USMS?
- Preliminary Findings for Nanomaterials
- What's Next?

# What is the U.S. Measurement System?



Context for
Evaluation of Barriers
to Technological
Innovation

# What is the U.S. Measurement System?

The United States Measurement System (USMS) is:

- All the people and institutions, private and public, that develop, provide, use, or serve to insure the validity of measurements
- A broad and autonomous system which encompasses:
  - **Measurement research and development**
  - **Measurement technology providers and users – in both the public and private sectors**

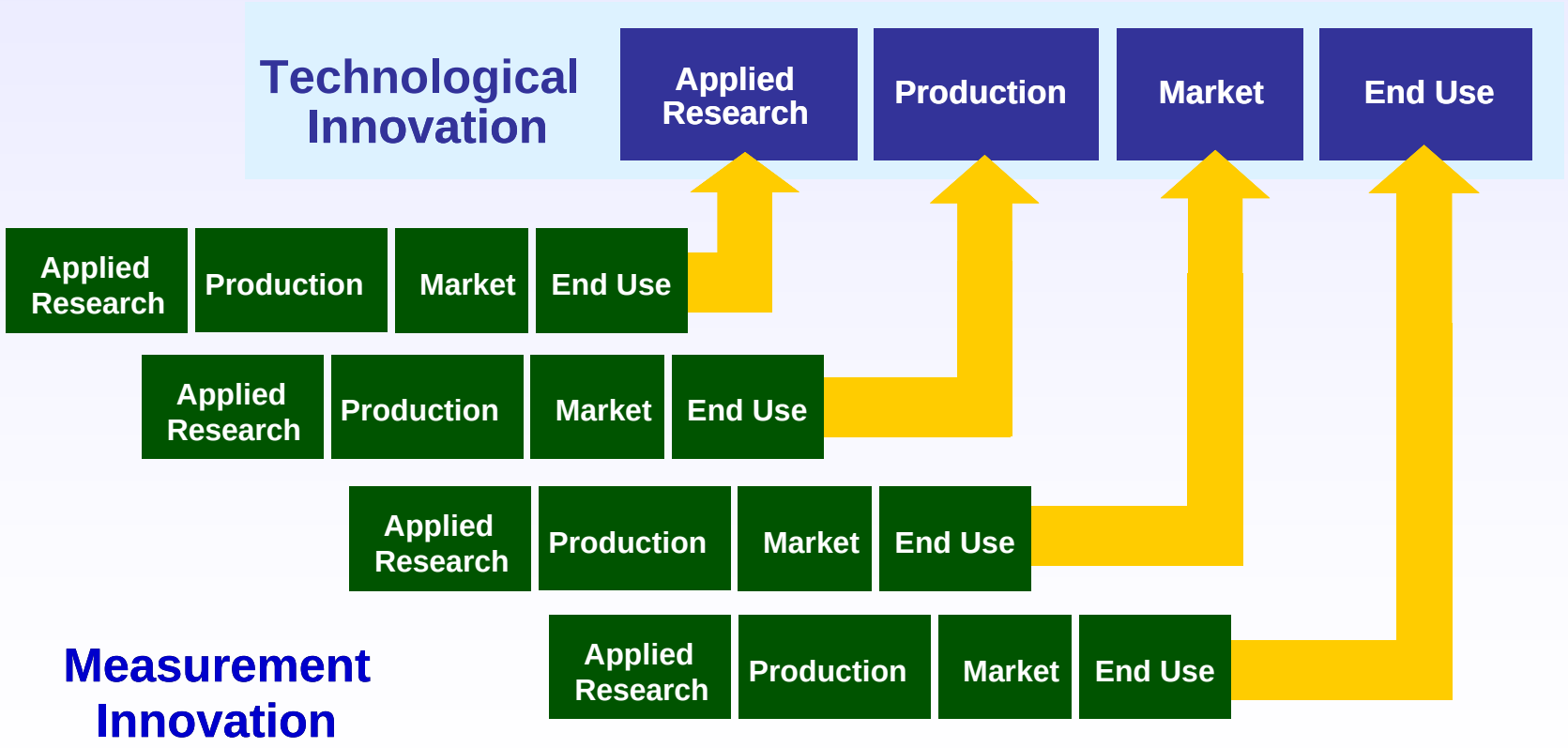
USMS "providers" include the national measurement institute (NIST, in the United States), calibration laboratories, accreditation services, weights and measures regulations, and other elements, situated within—and operated in support of—the broader USMS.

Everyone in the U.S. depends upon measurements in a myriad of ways every day

No one is in charge – no institution, no individual has authority over the system that produces those measurements

The USMS relies on, but also contributes to, the scientific research enterprise.

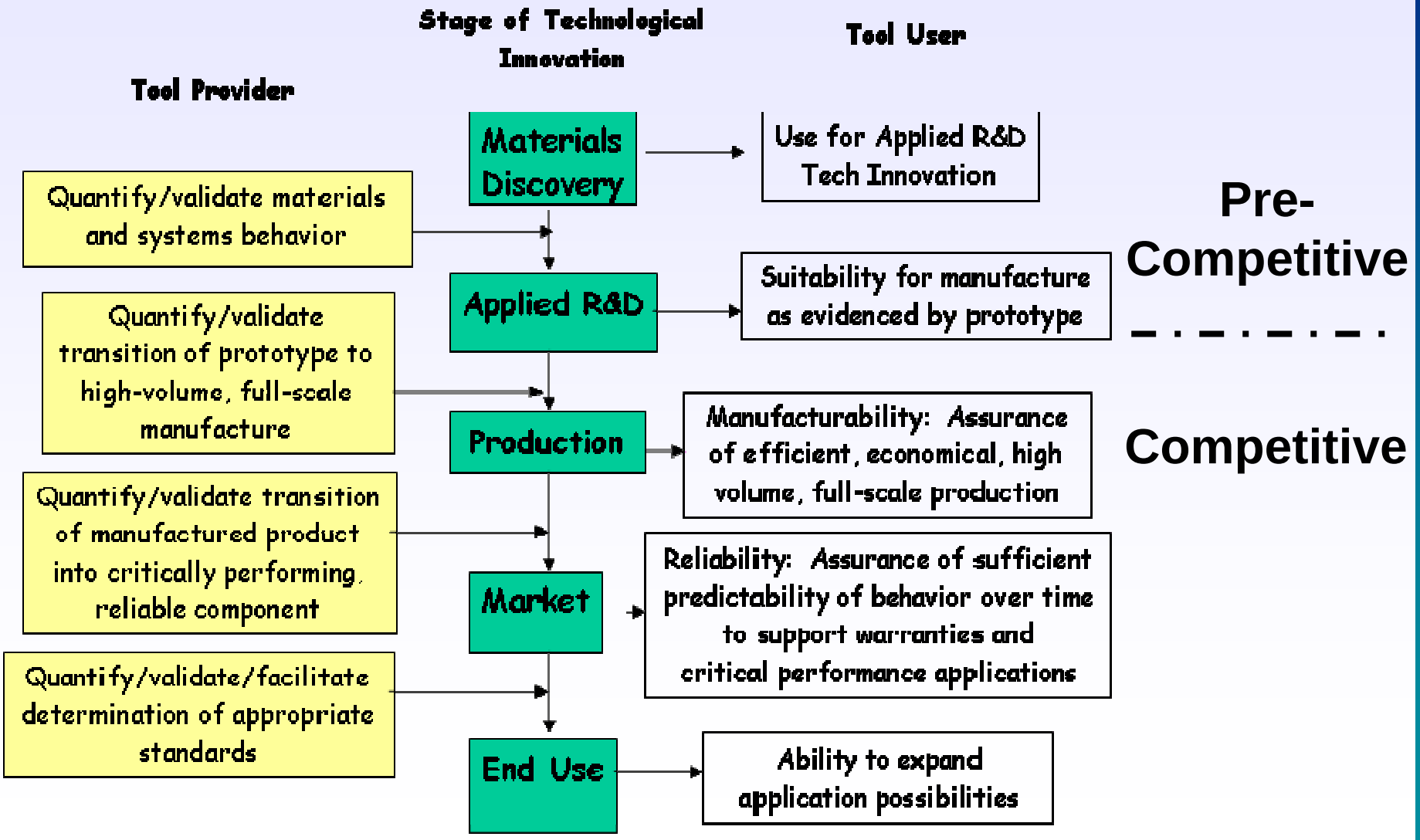
# NIST USMS Model of the Process for Generation of Measurement Solutions to Measurement Barriers to Technological Innovation



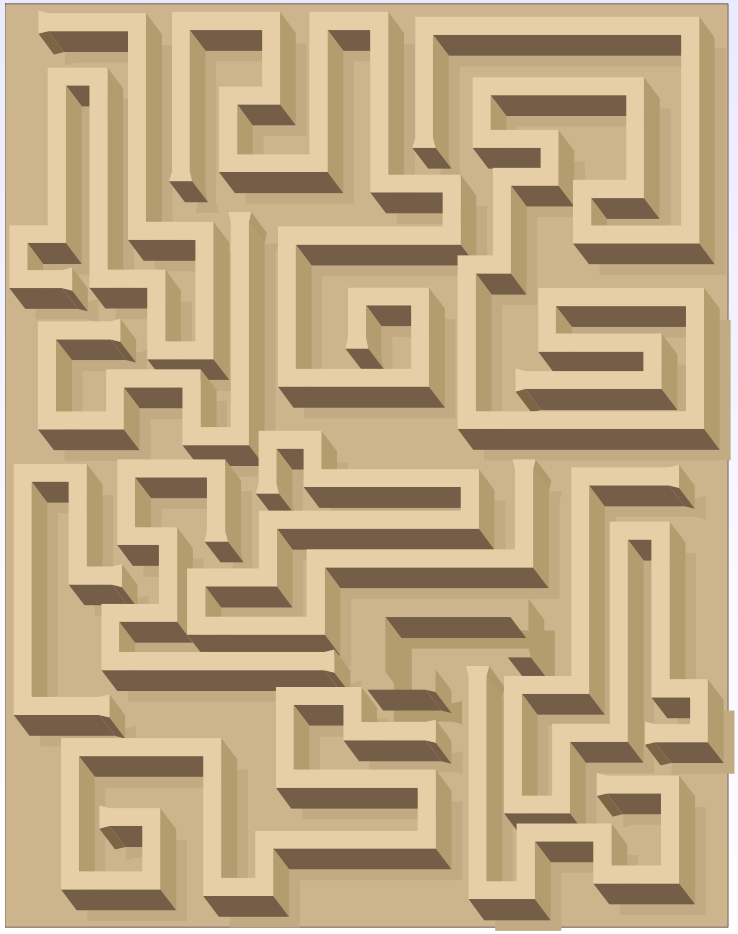

**Measurement Problems may be Barriers to any Stage of Technological Innovation, and may be Innovations Themselves**

# Stages of Technological Innovation:

## Accelerate Product Development via Increased Understanding of Measurement Issues across all Stages



# Why Assess the U.S. Measurement System?



Competitiveness in Innovation

# A Sense of Urgency, An Economic Imperative

## Assessing the U.S. Measurement System

- **Why?** Ensure that capabilities required by science and industry to accelerate innovation are available, under development, or planned
  - Identify measurement infrastructure needs
  - Identify system gaps and weaknesses
  - Engage stakeholders in search for solutions
- **What's the Risk?** Without an advanced measurement system, U.S. risks serious declines in competitiveness and quality of life
  - Other nations view measurement capabilities as source of potential advantage

# Why NIST?

NIST has committed itself to insuring that the measurement needs of the U.S. are met by taking a look at the whole of the nation's measurement system

Innovation in technology is a major source of the nation's economic well-being and military strength and is a basis for increased competitiveness, productivity, and quality

Most of U.S. industry's most critical needs in measurements pose barriers to economically important technological innovation and an assessment of the USMS can be based on a survey and analysis of those needs

It is expected that the assessment will bring the attention of industry and stakeholders to bear on systemic problems within the system, mobilize providers of solutions to specific measurement problems, and catalyze the identification of other needs and problems

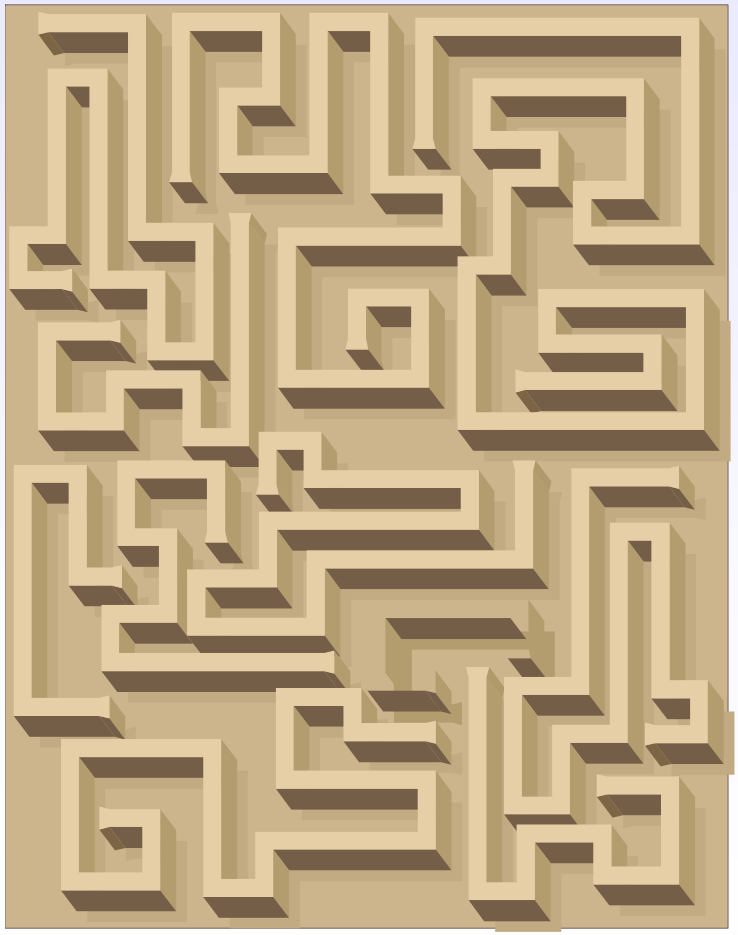
# Measuring Up To the Nation's Innovation Challenge
# The US Measurement System

## A Matter of Competitiveness: Addressing Measurement Barriers to Accelerate Innovation

"America's economic strength and global leadership depend in large measure on our nation's ability to generate and harness the latest in scientific and technological developments and to apply these developments to real world applications."
*--President's American Competitiveness Initiative*

Measurements are fundamental to the nation's capacity to innovate

# How do we Assess the U.S. Measurement System?



Measurement Needs

Authentication

Findings

Communication

# The USMS Assessment

**NIST Conducted a Fact-Based Assessment . . .**

- Reviewed 164 Industry Technology Roadmaps
- Conducted 15 NIST-Industry Workshops
- Interviewed Industry Representatives
- Solicited Input from Businesses and Trade Associations
- Hundreds of Participants from Industry, Universities, and Government

**. . . Obtained 723 Measurement Needs in 11 Industry Sectors and Technology Areas**

- Representative Sample of Barriers to Innovation

# The Datum of Input to the USMS Assessment: An Industry Measurement Need (MN)

Technological innovation at stake

Economic significance of the innovation

Technical barrier to the innovation

Stage of innovation at which technical barrier appears

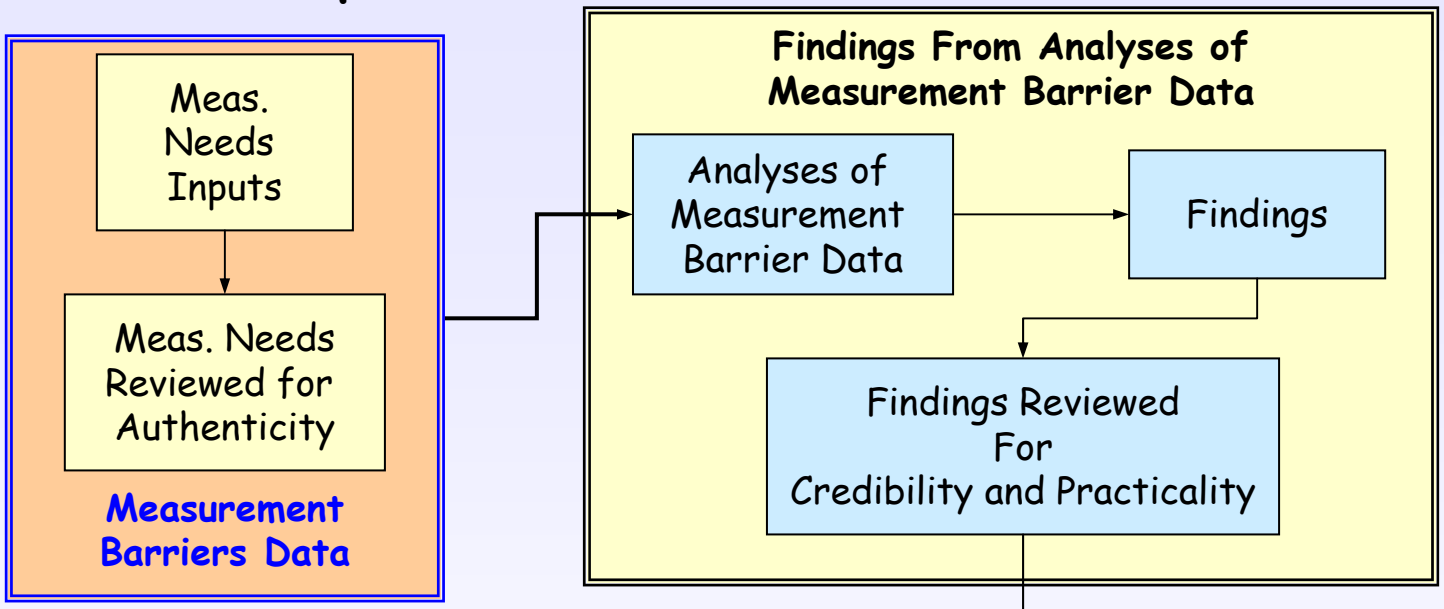
Measurement-problem part of the technical barrier

Potential solutions to the measurement problem

Potential providers of these solutions

Government role, if any, in these solutions

# Path for Assessing the State of the USMS Measurement Barriers to Technological Innovation



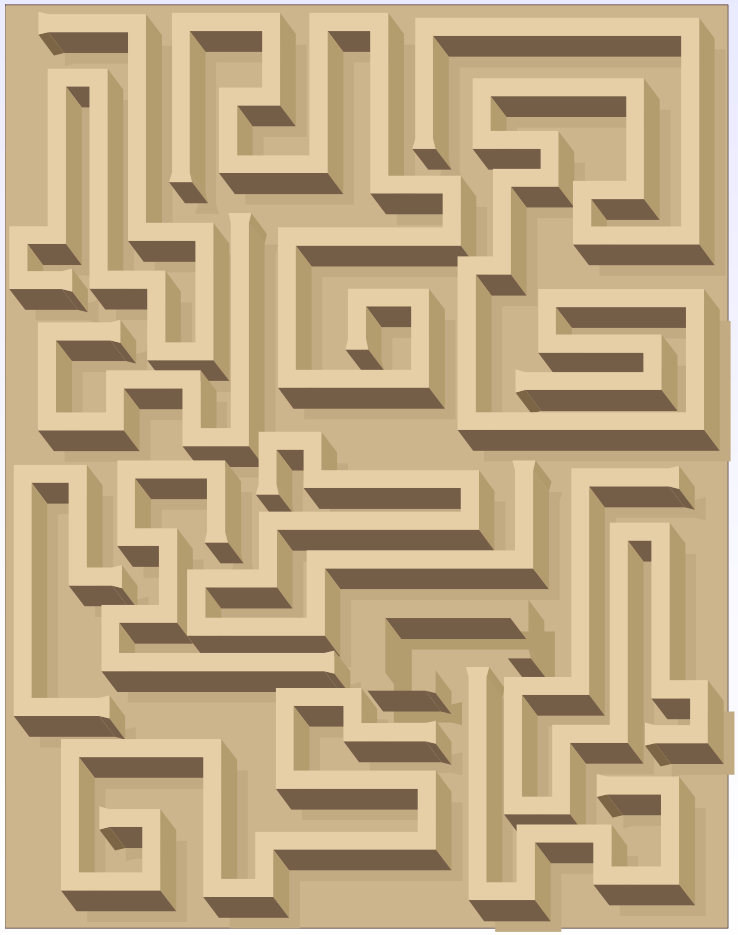

Inferences Drawn from Findings On the Capability of the USMS To Support Technological Innovation

**Sector/Technology Areas:**

**Materials**
**Nanotechnology**
Electronics, Semiconductor
Electronics, Non-Semiconductor
Healthcare
Energy, Power and Environment
Manufacturing (Discrete), including Automotive
Building and Construction
Defense and Homeland Security
Chemicals and Continuous Manufacturing
IT Software

Over 700 measurement needs were identified in 11 sector/technology areas, with input from 322 individual measurement needs and 162 technology roadmaps

# Preliminary Findings



General

Nanomaterials

# Measurement Needs Cross Both Sectors, Technologies

**Needs Across 11 Sector/Technology Areas for…**

- Increased Accuracy, Resolution
- Fundamentally New Measurement Methods
  - Some Existing Capabilities Pressed to Their Limits
  - Advances in Science & Technology, Changes in Society Require Novel Responses
- Affordable, Accurate Sensors for Real-Time Process Monitoring and Control
- Standards and Metrics for Evaluating System-Level Performance
- Practical, Cost-Effective Methods to Demonstrate Regulatory Compliance

# Complementary Challenges and Requirements

Measurement needs across the sector/technology areas would seem to vary tremendously, yet…..

Requirements to improve process control transcend nearly all sectors and demand increased accuracy, precision, resolution, sensitivity, and repeatability

Opportunities to use sensors to detect, monitor, and control a wide variety of quantities, properties and processes—in real time—are abundant

Reliable metrics for quantifying overall system performance—such as interoperability and conformance to specifications—are critically needed, as products and services are integrated or networked into collections of hardware and software technologies, including complex systems

# Nanotechnology Measurement Needs

54 Measurement Needs

49 Roadmap measurement needs in 10 Roadmaps

Major Nanomaterials Themes

- Nanoparticles, including nanotubes (17)
- Nanoelectronics/nanomagnetics (27)
- Reliability (6)
- Imaging/mapping (10)
- Nanomanufacturing (24)
- Nanobiomaterials, including drug delivery (9)

## Nanotechnology – Technological Innovations at Stake

Vastly increased digital data storage capacities

Smaller, faster, more power-efficient electronic devices

Advanced drug delivery systems

High-capacity fuel cells

New families of high performance catalysts, sensors, and actuators

Reliable, robust nanostructures

Higher performance MRI and NMR

Advanced scanning probe microscopy for nanoscale mapping

Nano-composite materials with increased thermal stability and reduced flammability

# Nanotechnology – Measurement Needs

Demand for new advanced measurement instrumentation for

- Accurate high-resolutions characterization of physical, chemical, and biological properties of materials at nanometer dimensions

Limits in abilities not only to measure key properties, but even to identify which key parameters must be measured

- Need to measure against anticipated (rather than existing) regulations

Creation of measurement tools to make rapid measurements of the properties of nano-materials and nano-devices related to their functional performance

Innovative approaches to measurement of nanoscale physical and chemical properties – especially where fundamental limits of current measurement techniques are being approached

# Barriers to Innovation – Measurement Needs in Nanotechnology

*Nanotechnology exemplifies the challenge in emerging technologies. It is a measurement-intensive and still largely experimental domain. Measurement solutions will open the way to deeper understanding and, ultimately, to new applications and markets.*

*Entirely new methods of measurement are required to characterize properties and attributes of nanomaterials, devices and structures, and the link between these properties and functionality.*

# Materials – Measurement Needs

- Creation of measurement instruments and methods capable of accurately characterizing the behavior of complex materials systems and structures
- Capabilities to evaluate performance and reliability of new materials successively for both production and market stages
- Capabilities for measuring the growing complexity of materials systems, structures and their interfaces
- Greater accuracy, better data and data collection and retrieval, more fundamental knowledge and better resolution
- Measures for the processes needed to improve production efficiency in terms of cost, time and energy

# Nanomaterials and the USMS Assessment: Observations

Nanotechnology appears to have a particularly high demand for new advanced measurement instrumentation, to provide **accurate, high resolution characterization of physical, chemical and biological properties of materials at nanometer dimensions**

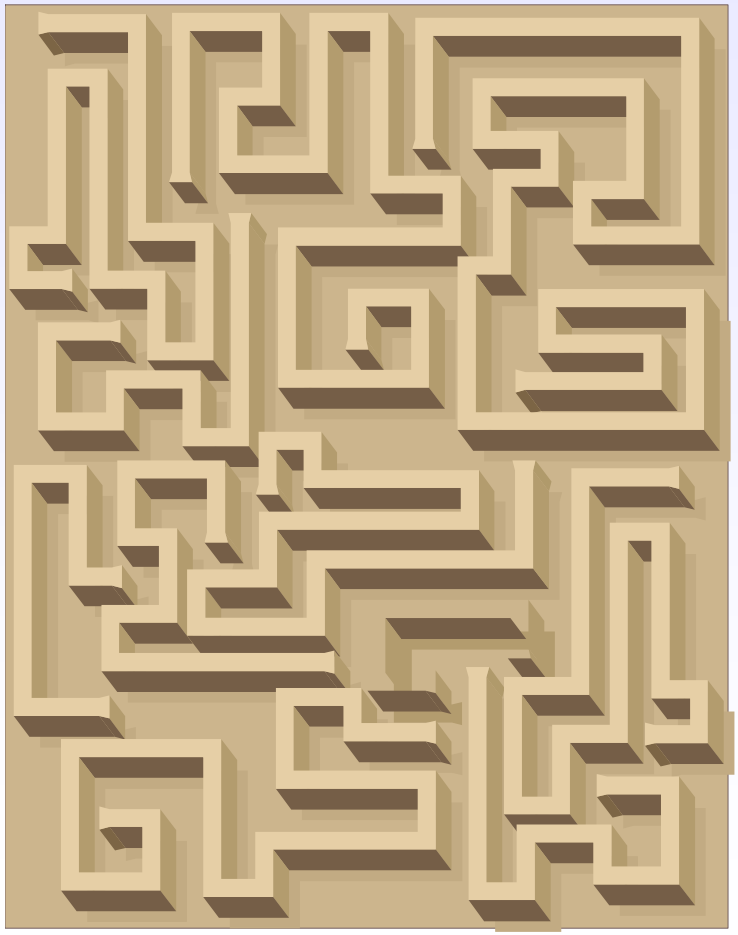
The **absence of regulations** is having a serious impact on the innovation process, limiting Industry not only in its ability to measure key parameters but also in its ability to identify which key parameters must be measured to meet future regulations

A principal measurement barrier to technological innovation is the absence of measurement instruments, techniques and methods capable of **accurately characterizing the behavior of complex materials systems and structures**

The **timely delivery of materials measurement solutions** is increasingly challenged by the growing complexity of materials systems and structures and their interfaces

A key factor driving the need for measurement innovation is the anticipation of the production/marketplace need for the evaluation of **Materials Performance, Manufacturability, and Reliability**

# What's Next?



Example: Nanocomposites

In-depth Analysis of Findings

# Example: Nanocomposites

Workshop: ***Instrumentation and Metrology for Nanomanufacturing***, October 17-19, 2006, NIST, Gaithersburg, MD

Four areas of Nanomanufacturing

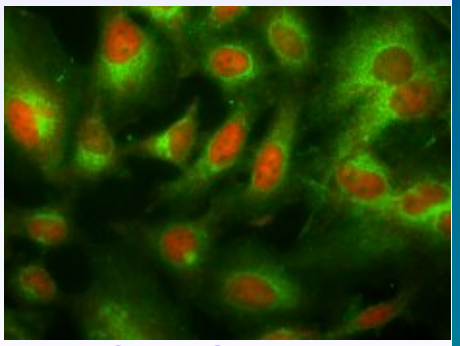
- Nanocomposites
- Electronics
- Chemicals
- Healthcare / Bio

# Large-scale U.S. production of nanotechnology-based products is limited by:

Insufficient understanding of materials and system behavior, particularly with respect to size / scale-up, to consistently and efficiently **manufacture** nanoscale products

Insufficient understanding of materials properties and systems performance to predict behavior over time of **reliable** nanoscale products

Insufficient **measurement technology** to quantify nanoscale materials and product behavior with respect to both size and time



QDot Sensors

# Why is the problem hard?

At very small length scales, surface effects become comparable to bulk properties in determining or predicting nanoscale behavior

- As surface effects become more dominant, the need for their quantification becomes critical (i.e. no longer acceptable to use bulk properties alone)
- Until surface effects are understood, measurable and predictive of behavior, it will be extremely challenging to enable sufficient understanding of materials / system behavior to support a critically-performing product

Processing and performance environment and other system components affect nanoscale behavior

- These effects also change with time, thus challenging the ability to predict behavior over time, and in particular performance environments, ensuring the reliability of nanoscale products
- Mechanisms affecting reliability will often be different at the nanoscale (e.g. defect mobility)

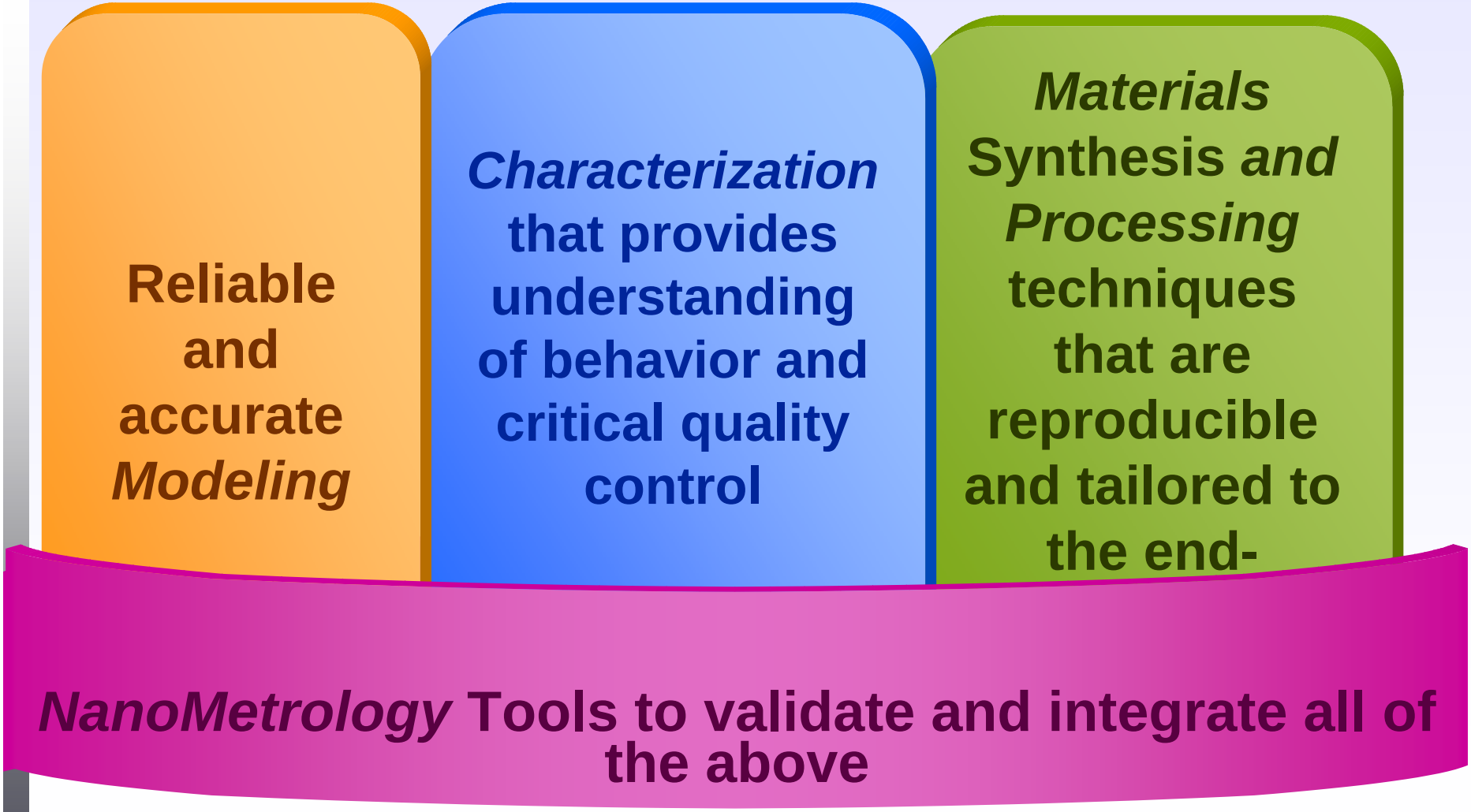
Measurements at very small length scales are difficult due to the need for enhanced sensitivity and resolution, as well as complementary abilities such as:

- Mapping of changes in performance
- Visualization of changes in-situ

Current microscale measurement technologies can rarely be extrapolated to the nanoscale

**Today's approaches are not as efficient or effective as they need to be**

# The 4 pillars of NanoMaterials



# Some 'Big Picture' Conclusions— The USMS and Innovation

- US Measurement System must progress in concert with the international system to avoid impediments to export markets.
- Breakthroughs in measurement capabilities are critical to US success in emerging technologies, requiring sustained progress **in fundamental measurement science**.
- Success of US innovation efforts ultimately hinges on the timely availability of cost-effective, production-ready measurement tools.

# The USMS - NIST and the Future

NIST will continue to provide measurement solutions through cutting edge research, calibrations, standard reference materials, standard reference data, laboratory accreditation, and technology transfer

NIST will continue to provide leadership for the USMS

- Collect new Measurement Needs
- Work with external stakeholders to identify needs
- Collaborate with solution providers to develop solutions needed for priority Measurement Needs
- Report on state of USMS

The U.S. Measurement System will continue to work with external stakeholders to meet measurement needs

# Next Steps

## USMS Assessment Is a Beginning, Not an End

- Inform NIST's strategic planning and actions to meet Nation's priority measurement needs affecting innovation
- Catalyze efforts to identify and prioritize measurement needs that limit innovation and competitiveness in areas beyond the scope of this initial assessment
- Cultivate broad awareness of the national importance of a robust, forward-looking measurement infrastructure
- Partner with public- and private-sector stakeholders to focus attention and *action* on most significant measurement barriers to innovation

# How May the USMS Assessment be used to Enhance Communication with our Customers?

- Measurement needs
  - Submission of new measurement needs
  - Authentication of existing measurement needs
- Findings
  - Authentication
- Workshops
  - Participation
  - Leadership
- Input regarding potential NIST Initiatives
- Your ideas?